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A FIVE-YEAR RECORD OF LIGHTNING STORMS AND FOREST FIRES

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According to the records compiled by the supervisors of the national forests in the northern Rocky Mountain region, lightning has been responsible for a greater number of fires, more burned area, more damage, and more expense of suppression in this territory than all other causes of forest fires combined. Smokers, campers, brush burners, incendiarists, lumbering operations, and railroads combined start annually an average of 379 fires on these 23,000,000 acres of Federal forest land, but lightning is credited with an annual average of 824 fires during the 10-year period, 1919 to 1928. In 1926, which is accepted as one of the worst seasons for lightning fires, 311,607 acres of Federal, State, and private forest land in Idaho and Montana were burned over by fires started by lightning. The damage on this area was evaluated at $3,572,000, while the Federal Government alone spent approximately $948,000 for fire suppression.

These conditions have long been recognized as one of the major impediments to successful lumbering and forestry. As lumbering, which must depend in the future upon forestry, is one of the basic industries in this section of the country the economic importance of lightning storms is obvious. It is apparent that no industry subjected to such a chance of loss as has been indicated can operate as cheaply and efficiently as it could if the danger were fully understood and at least partially controlled.

Early in 1922 the Northern Rocky Mountain Forest Experiment Station commenced an investigation of lightning storms, working in cooperation with the Forest Service administrative organization, which had studied the occurrence of lightning-caused forest fires ever since the national forests were created. The administrative study had localized the danger both in time and by area, but it had not attempted to investigate the storms which are the causes of these fires. The research project, initiated in 1922, has been conducted for the purpose of assembling more and better information concerning the occurrence and characteristics of these storms which cause so much loss and expense.

As Morrell has pointed out (**11**) [1] the possibility of improving forest protection lies chiefly in reaching forest fires quickly and attacking them before they get large, with an adequate and properly equipped crew of men. Forest fires can be attacked with speed if they are few in number, or even when numerous, if the forest protective organization has a reasonably definite warning that such fires are probable. If warnings are available, men engaged on other work can be moved to locations more strategic for fire suppression, and additional men can be hired specifically for such an emergency. But when a single national forest of 600,000 acres, such as the Kaniksu in northern Idaho, is visited without any warning by lightning storms, that in one day start over 150 forest fires, as occurred on July 12, 1926, no forest protective organization is able to expand fast enough to cope with the situation. Under such conditions several fires are certain to be left without attention long enough for them to become so large that they spread as conflagrations through the crowns of the trees. One such crown fire often burns over more area, destroys more timber, and, after it drops to a ground fire and becomes approachable, often costs more for its suppression than a hundred or even a thousand other forest fires which are reached and extinguished before they have an opportunity to attain such momentum.

Such occurrences make very clear the importance and profitable application of warnings of lightning storms, especially if the warnings could be made available two or three days in advance, and could cover not only storm occurrences but also storm fire-starting probabilities. With such warnings action could be taken that would in nearly all cases reduce lightning fire damage and expense to a very satisfactory minimum. Even at present, with the weather predictions limited to a period of 36 hours and with no indications contained in the forecasts concerning the fire-starting characteristics of the storms, considerable progress is being made. Present investigations have contributed materially toward more accurate forecasts by obtaining more detailed records of storm occurrence. They have also found (**5**) that the types of storms which commonly start many fires can be distinguished from the types which do not start many fires. Furthermore, methods have been developed for measuring forest inflammability so that the danger of ignition and rapid spread can now be determined as a basis for administrative action (**6**).

The data herewith presented add to previously published information on lightning storms in this region largely through the increase in evidence on which the deductions are based. Some of the conclusions previously stated must now be slightly modified, but many are greatly strengthened by these 14,754 reports covering a 5-year period, as compared to the 3,800 reports for two years used as a basis for the first report. Some new aspects of the situation are also apparent in this greater volume of data.

[1] The **boldface** figures in parentheses refer to literature cited.

OCCURENCE OF STORMS

One of the outstanding discoveries resulting from this study is the knowledge that lightning storms are far more frequent in the forested sections of this region than previous records, largely obtained at low-elevation non-forest stations, had indicated. The present records, which are most complete for July and August, less complete for June and September, and fail entirely to cover the other eight months of each year, give for the region as a whole an average of 88 thunderstorm days each season, for the five years studied, as follows: 1924, 85; 1925, 95; 1926, 83; 1927, 87; and 1928, 88 days. For this same region Alexander's compilation, (2) which is quoted by most meteorological authorities, records only 10 to 30 thunderstorm days per year at individual Weather Bureau stations of the first order.[2]

FIG. I
MAP OF THUNDERSTORM OCCURRENCE.

AVERAGE NUMBER OF THUNDERSTORM DAYS EACH SUMMER. FOR GROUPS OF NATIONAL FORESTS. BASED ON RECORDS 1924-1928 INCLUSIVE. FOR NORTHERN IDAHO AND WESTERN MONTANA AS A REGION THESE DATA INDICATE AN AVERAGE OF AT LEAST 88 THUNDERSTORM DAYS PER YEAR.

This large increase in storm occurrence, indicated by the Forest Service data, is partly explained by the fact that the region has been treated as a unit, whereas Alexander's summary considers each observation station as a unit. Compilation for relatively large areas is justified, however, by the fact that fire-protection work is administered by Federal and State officials for areas seldom less than a hundred thousand acres and usually comprising many millions of acres. Weather forecasts also are usually worded to apply to large areas, half a State or more, and consequently must be based upon and should be rated according to the records of many stations. In this report relatively large areas are consequently treated as units.

Another important reason why the present summary shows more thunderstorm days than other records is the recognized more frequent occurrence of lightning storms over forested, mountainous areas, in contrast to their frequency over low elevation, valley or plains stations such as Spokane, Kalispell, Helena, Lewiston, etc., where the regular Weather Bureau observations are made.

The large number of thunderstorm days reported is also explained by the fact that the Forest Service observers used in this study consisted largely of the lookout men stationed on 270 or more high mountain tops continually scanning great areas and wide horizons for the streamers of smoke that locate forest fires. From these high points it is almost impossible for a thunderstorm to occur within 30 or 40 miles of a station without being seen or heard by the observer. It is probable that few, if any, storms escape detection during July and August, when these observatories are all occupied.

A fourth reason why the present data show more storm days than indicated by other sources of information may be that thunderstorms have been more frequent during the past few years. Such is the local opinion, but the lookout-station records do not cover a sufficient number of years to give either support or denial to this belief.

When the regional data obtained in this study are subdivided into smaller units, such as groups of national forests, a marked reduction in thunderstorm frequency is shown; yet even the totals surpass those based on observations at low-elevation stations largely outside the forests. The frequency for these small groups of forests is shown by Figure 1; and Table 1 permits comparison of these figures with those resulting from carrying the subdivision down to individual national forests.

TABLE 1.—*Relation of number of thunderstorm days to number of lightning fires per 100,000 acres for individual forests and forest groups in the northern Rocky Mountain Region*

Group and forest	Thunderstorm days, by years [1]						Fires per 100,000 acres annually
	1924	1925	1926	1927	1928	Average	
							Average number
Group I:							
Beaverhead	41	61	27	45	41	43	0.3
Deerlodge							.8
Helena	21	29	32	33	32	29	1.2
Average						[2] 56	1.0
Group II:							
Bitterroot	23	36	22	34	25	28	2.6
Lewis and Clark	15	36	32	39	19	28	.2
Missoula	23	31	28	44	39	33	1.7
Average						[2] 43	2.0
Group III:							
Blackfeet	15	20	28	35	36	27	6.8
Cabinet	9	27	24	44	40	29	4.7
Flathead	26	25	33	49	54	37	5.0
Kootenai	14	30	41	43	40	34	9.1
Lolo	20	41	34	42	44	36	3.5
Pend Oreille	20	24	26	37	40	29	5.5
Average						[2] 62	6.0
Group IV:							
Clearwater	17	35	25	28	33	28	15.1
Coeur d' Alene		33	26	50	40	37	6.9
Kansiksu	18	26	23	38	37	28	15.3
St. Joe	23	24	20	30	34	26	8.8
Average						[2] 50	11.0
Group V:							
Nezperce	29	61	47	40	41	44	3.6
Selway	30	26	44	47	55	40	7.6
Average						[2] 57	6.0

[1] Records for period June to September. June and September data are fragmentary.
[2] Group averages are higher than the averages for the forests (as explained in the text), since two or more forests may or may not report storms the same day.

These data show that on areas as large as a national forest, or a group of forests, thunderstorm frequency has been double to quadruple that indicated by W. H. Alexander's isoceraunics (ibid.) in this region. This does not imply any inaccuracy in the Weather Bureau reports,

[2] This is also true of other parts of the western third of the United States.—ED.

but it emphasizes the need for detailed records from the forested mountain areas and for special analyses of such data as a basis for forest-fire weather predictions.

In estimating the danger resulting from lightning storms one might easily be led to believe that the group of forests having the most frequent exposure to lightning as shown in Figure 1 would have the greatest number of fires per unit of area. On such a basis the Kootenai-Cabinet-Flathead-Pend Oreille-Lolo group, with 62 thunderstorm days per year, should show the greatest number of lightning fires per 100,000 acres; but Table 1 shows that this is not the case.

The fact that the number of lightning fires per unit of area is not entirely dependent upon frequency of thunderstorms, is clearly shown by this comparison of data. This lack of correlation can also be shown for the region as a whole when the records for each of the past five seasons are compared. For example, an increase of 12 per cent in the number of storm days from 85 to 95, resulted in an 80 per cent increase in the number of lightning fires, from 1924 to 1925. In 1926 the number of storm days decreased 2 per cent, but the number of fires increased 42 per cent, as compared to 1924. In 1927 there were 2 per cent more storm days, but 28 per cent more lightning fires than in 1924. In 1928 there were 3½ per cent more storm days and 14½ per cent more fires than in 1924. Hence, it appears that regardless of whether the problem is considered by groups of forests, or by years, thunderstorm frequency alone is not a dependable criterion of the probability of lightning-caused forest fires.

This information indicates that forecasts of thunderstorm days are not sufficient as a warning of lightning-fire danger. Additional information is needed for the region as a whole as to the extent and the character of the storms each day. The importance of extent of the storms is demonstrated by Table 2, which shows that as more and more stations within the region report storms in one day, the proportion of reports indicating fire-starting storms increases very rapidly. When there were few storms—only 1 to 10 stations reporting them—usually less than one station per day, or about 5 per cent of the reporting stations, stated that fires resulted. When there were widespread storms—from 201 to 304 station reports in one day— approximately 71 reports, or about 28 per cent, stated that fires resulted.

TABLE 2.—*Comparison of fire-starting storms with thunderstorm days reported, on basis of number of stations reporting storms, 1924–1928*

Stations reporting storms in one day	Thunderstorm days reported, 1924–1928		Reports of fire-starting storms	Reports of fire-starting storms per thunder storm day
	Number	*Per cent*	*Number*	*Number*
1 to 10	239	54	65	0.27
11 to 20	45	10	63	1.4
21 to 30	29	7	105	3.6
31 to 40	23	5	82	3.6
41 to 50	12	3	69	5.8
51 to 60	10	2	86	8.6
61 to 70	11	3	153	13.9
71 to 80	10	2	128	12.8
81 to 90	9	2	182	20.2
91 to 100	3	1	85	28.3
101 to 120	13	3	230	17.7
121 to 140	7	2	238	24.0
141 to 160	7	2	195	27.9
161 to 200	9	2	345	38.3
201 to 304	11	2	776	70.6
Total	438	100		

It is apparent from this compilation that the fire problem was almost negligible on 54 per cent of the thunderstorm days during the past five fire seasons, when from 1 to 10 stations reported storms each day. However, on 45 days, when from 11 to 20 stations reported storms, there was an average of at least one report that fires resulted. When from 21 to 30 stations detected storms there were nearly 4 reports each day stating that fires resulted. As one report of a fire-starting storm always means that from one to several fires were discovered, it is obvious that the occurrence of fires increases with the number of stations reporting storms, and that the need for forecasts increases in the same way. From the evidence available it appears that whenever less than 40 stations have reported storms in this region in one day no marked regional danger resulted. This might be accepted tentatively as an approximate measure of the need for regional forecasts, the greatest need beginning whenever more than 40 stations are apt to report storms in one day.

Table 3 cites the exact dates, during the 5-year period studied, when more than 40 stations reported the occurrence of lightning storms. This tabulation may be of research value in the study of conditions which have during this period caused greatest forest-fire danger in this region.

TABLE 3.—*Occurrence of dangerous thunderstorm days by number of stations reporting storms*

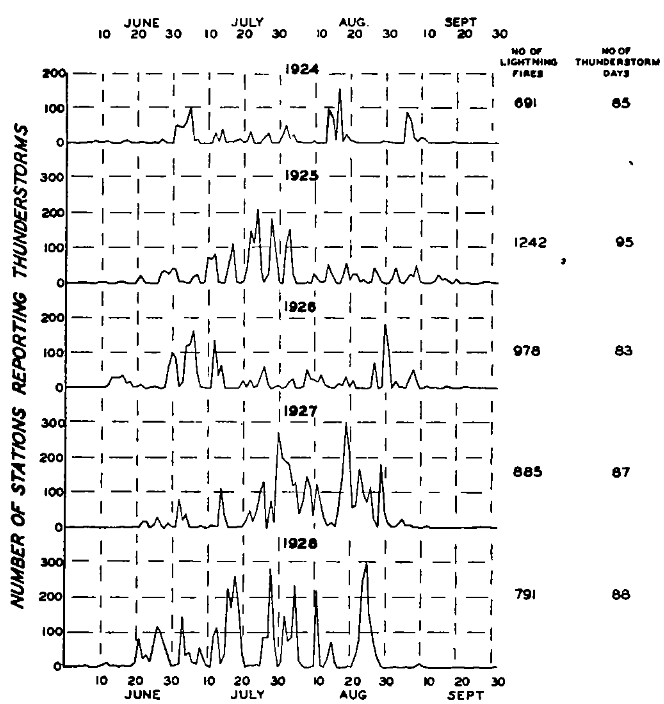
Number of stations reporting storms	Date of occurrence of storms				
	1924	1925	1926	1927	1928
41 to 60	July 1, 2, 3. Aug. 1	June 30 July 21, 25 Aug. 13, 18, 26 Sept. 1, 7	July 7 Aug. 8 Sept. 6	July 22, 24 Aug. 16, 20, 29	July 5, 8.
61 to 80	July 4 Aug. 14 Sept. 5	July 10, 11, 16	June 29 July 1, 14, 26 Aug. 26	July 28 Aug. 6, 11, 21	June 25, 28. July 29. Aug. 2, 14, 26.
81 to 100	July 5 Aug. 13 Sept. 4	July 12		July 2 Aug. 23	June 2. July 12, 26, 27. Aug. 3, 22.
101 to 150		July 17, 23, 29 Aug. 1	June 30 July 4, 5, 12	July 14, 25, 26 Aug. 3, 4, 7, 8, 10, 17, 25.	June 26, 27. July 4, 13. Aug. 1.
151 to 200	Aug. 16	July 22, 28 Aug. 2	July 6 Aug. 29	Aug. 1, 2, 22, 28	July 17, 19. Aug. 25.
201 to 250		July 24		July 31 Aug. 19	July 16. Aug. 4, 10, 23.
251 to 304				July 30 Aug. 18	July 18. Aug. 24.

The occurrence and extent of storms are also shown graphically in Figure 2, which reveals, better than a tabular statement, the relation of the days with few reports to the days of widespread occurrence of storms. It is believed that such information should serve as a basis for the study of the weather types that result in storms in the northern Rocky Mountain region, as Alexander (1) has done for the State of Washington. Such work, however, which may prove to be extremely difficult, as pointed out by Henry (8), is more a field for meteorologists. No attempt is made in the present report to analyze this phase of the problem. It is evident, however, that such analysis is basic to most accurate forecasting, and that the collection of field data by the Forest Service should be designed to supply all possible information needed by the Weather Bureau.

CHARACTERISTICS OF STORMS

Although it has been shown that the more widespread the occurrence of thunderstorms the greater the proportion that are reported as starting fires, more information than this must be available to the forest protective organization in order to determine whether exceptional action is needed to meet the danger most efficiently. Some of the factors involved are entirely independent of the thunderstorms, and include the timber type (**13**), the prevalence of inflammable fuels, the seasonal dryness and inflammability of these fuels, and the character of the weather during the preceding days and weeks. These factors are important because green trees, unless covered with lichens, do not ignite as readily as dead trees, or snags. There are more chances of ignition where the volume of dead wood is great than where there is less dead and down wood. Early in the season most of the forest materials are usually considerably wetter, both on the surface and in the interior of the piece, and consequently less inflammable than during late August and early September. Likewise, if recent rains have moistened the forest fuels, or if recent hot spells have dried them, the results of a certain storm or a certain number of storms may differ greatly. All of these factors are recognized by forest protective organizations, and the importance of predictions of lightning storms is rated accordingly.

FIG. II.
OCCURRENCE OF THUNDERSTORMS.



The storms themselves also vary so much that no two may be expected to produce similar results, even though both might theoretically cover equal areas of similar timber type, fuel volume, fuel inflammability, etc. Every experienced forest officer recognizes this fact and knows that there are certain characteristics which distinguish generally safe storms from prolific fire starters. For example, it is obvious that storms with more than the usual number of flashes and with a large percentage of the bolts striking the ground will start more fires than storms with only few flashes, and those largely confined to the clouds. It is also obvious that if the storm brings only a light rain of short duration more fires are apt to result than if the rain is heavy and of long duration. The present study has shown that it is possible to determine average values of these characteristics so that they may be recognized and rated specifically and uniformly by all observers.

Alexander (**1**) has stated, basing his remarks on a few reports for the State of Washington, that the percentage of flashes reported as having been confined to the clouds and the total number of flashes in each storm (the latter not always stated) do not offer a very reliable basis for a comparison of percentages as between "safe" (nonfire-causing) and dangerous (fire-causing) storms and can not at present be given much weight as determinants of the safety factor. He finds a similar lack of authority in reports of the duration of precipitation before and after the flashes. A mathematical analysis of the several thousand reports available for the northern Rocky Mountain region, however, does not support his contention. The analysis shows that the general electrical and rainfall characteristics of lightning storms can be observed by field men and that average conditions can be specified, departures from which will indicate whether the storms being observed are apt to cause more forest fires or are apt to be less troublesome, in this region.

It is highly desirable that these characteristics be determined so that inexperienced lookouts and rangers will be better able to evaluate the degree of danger in the storms that they are observing, often hours before the lightning fires send up enough smoke to be detected. These few hours of possible preparation, between studying the storm and discovering the fires, often determine the difference between full preparation to cope with many fires and lack of that preparation, with resultant large expense and damage. So long as lightning storms do vary in their ability to start fires, and so long as the official forecasts can be expected merely to indicate that storms of some sort will occur, experience has shown that fire control can at present be improved by utilizing even the most generalized estimates of the fire-starting ability of lightning storms.

The present criteria of these conditions are admittedly no better than other mathematical averages based on a large volume of data. They serve, however, to evaluate conditions which are being and must be observed. They provide usable measuring sticks, crude as they may be, for the men who must use them. They represent what is believed to be the first attempt to evolve such criteria of thunderstorm danger, and like most first attempts, they are capable of considerable improvement. A new form of report has recently been devised, which is expected to constitute one small improvement, and the observers are continually being trained to produce more complete and accurate reports. Eventually, it is hoped to improve the data still more by the use of instrumental measurements.

PRECIPITATION

When this investigation was commenced in the northern Rocky Mountain region in 1922, and when the field report form was revised in 1924, an attempt was made to obtain observations of the rainfall with each storm, most of which are single cloud affairs often only a few miles in diameter. Only about half the storm clouds pass directly over observation points, even when these are but 20 miles apart, and consequently rain-gage measurements could not be depended upon to give data on all storms. However, lookouts at their high mountain-top station are frequently called upon by their supervising ranger to "size up" storms some distance away. Is it raining hard from the storm? How long has it been raining in Deep Creek? What drainages are getting soaked the best? These are typical questions asked of the lookout by his ranger. Therefore, on the new report form lookouts were asked for determinations of the number of minutes of rainfall ahead of the lightning, the intensity of the rainfall accompanying the lightning, and the number of minutes of precipitation after the lightning-bearing section of the storm had passed on, and, when the storm-cloud passes overhead, the actual measurements by rain gage.

Analyses of these data have shown that 92 per cent of the thunderstorms in this region are accompanied by some rain. Hence the information most urgently needed concerns the rainfall ahead of the lightning, which may moisten the fuels so that they will be too wet to ignite; and the rainfall with and following the lightning, which may extinguish any fires that do start. The analyses have failed to find any value in the reports of the intensity of the rainfall accompanying the lightning, and the original reports do not permit a determination of its duration. The other two features have been developed as follows, in Tables 4 and 5.

The outstanding feature of Table 4 is the determination based on 9,549 observations that with the average lightning storm in the northern Rocky Mountain region rain reaches the ground and moistens the fuels at any particular place for about 12 minutes before the lightning commences to flash over or to strike down to that point. This might be called the "scud rain," as it occurs ahead of the lightning-bearing portion of the cloud, approximately under the roll scud, and, as shown by these measurements, passes over very quickly.

TABLE 4.—*Record of rainfall ahead of the lightning in both wet and dry storms, 1924–1928*

Forest group [1]	Average number of minutes of rainfall by years						Basis, number of observations
	1924	1925	1926	1927	1928	All years	
Group I	7	8	9	4	12	8	662
Group II	6	12	9	16	13	13	864
Group III	12	8	21	11	10	12	4,012
Group IV	19	12	31	9	11	14	2,251
Group V	17	12	20	10	11	13	1,760
Region	13	10	21	11	11	12	9,549

[1] These groups of national forests correspond, with but two exceptions, to those used in the first report on this study, as follows: Group I, Beaverhead, Deerlodge (no data), Helena; Group II, Lewis and Clark, Missoula, Bitterroot; Group III, Blackfeet, Flathead, Cabinet, Kootenai, Lolo, Pend Oreille; Group IV, Clearwater, St. Joe, Coeur d'Alene, Kaniksu; Group V, Selway, Nezperce. The exceptions are the stopping of records from the Jefferson Forest, which was included in Group I of the first report, and the change of the Lewis and Clark from Group I to Group II, where its fire records assign it with most agreement.

TABLE 5.—*Record of rainfall following the lightning in both wet and dry storms, 1924–1928*

Forest group	Average number of minutes of rainfall by years						Basis, number of observations
	1924	1925	1926	1927	1928	All years	
Group I	42	25	42	33	44	29	651
Group II	15	34	28	38	30	31	855
Group III	46	29	70	34	33	39	4,010
Group IV	56	26	81	33	27	38	2,187
Group V	28	40	55	37	32	38	1,781
Region	40	31	64	35	33	37	9,484

The most important fact in Table 5 is the regional average for the 5-year period, showing that on the basis of 9,484 observations there is an average of 37 minutes of rainfall which may be counted on after the lightning has ceased to moisten the fuels and prevent the spread of fires caused by the lightning. This rainfall following the lightning probably is largely the so-called "secondary rain" described by Humphreys (**9**) in his analysis of the structure and behavior of thunderstorms.

In the preliminary investigation, based on the data for 1924 and 1925, averages of 11 minutes' rainfall ahead of the lightning and 33 minutes' following it were obtained. These averages were based on 2,455 reports. It is obvious from Tables 4 and 5 that the addition of data for three more seasons, raising the basis to over 9,400 reports, has not changed the first determinations materially.

Knowing the average duration of rainfall ahead of the lightning, and following it, the important question immediately arises: Do the storms that started fires show any appreciable differences in amount of rainfall when compared to storms that did not result in fires? The available data on this phase of the problem are shown in Tables 6 and 7. The number of reports used as a basis in these tables is less than shown in Tables 4 and 5, because many reports failed to state specifically whether or not the storm started fires.

TABLE 6.—*Record of number of minutes of rainfall ahead of the lightning in fire-starting as contrasted with nonfire-starting storms, 1924–1928*

Year	Nonfire-starting storms		Fire-starting storms	
	Average rainfall	Basis, reports	Average rainfall	Basis, reports
	Minutes	*Number*	*Minutes*	*Number*
1924	16	391	9	253
1925	9	718	8	426
1926	29	670	13	334
1927	12	1,622	7	575
1928	11	734	8	532
Total and average	14.6	4,135	8.7	2,120

This table shows an average difference of 5.9 minutes in the duration of the scud rain ahead of the lightning is dangerous as compared to safe storms. Although this is a small absolute quantity, it is proportionately very large (68 per cent of the 8.7-minute average); and it is also consistently true that each year the nonfire-starting storms have a greater average rain than the fire-starting storms. This being true, and considering the basis of 6,253 reports over a 5-year period, it seems entirely safe to conclude that there is an appreciable and a significant difference in the amount of the rainfall ahead of the lightning in safe and dangerous storms.

TABLE 7.—*Record of number of minutes rainfall following the lightning in fire-starting as contrasted with nonfire-starting storms, 1924–1928*

Year	Nonfire-starting storms		Fire-starting storms	
	Average rainfall	Basis, reports	Average rainfall	Basis, reports
	Minutes	*Number*	*Minutes*	*Number*
1924	50	414	34	257
1925	32	736	27	436
1926	74	695	44	338
1927	38	1,581	32	578
1928	37	730	23	529
Total and average	44.0	4,156	30.8	2,138

In Tables 7, again, for the secondary rain following the lightning, the data show 13.2 minutes, or 43 per cent longer rainfall for storms which did not start fires than for dangerous storms. Here, also, a large number of reports covering a 5-year period are used as a basis. And again the data are consistent; no average for any one year in the fire-starting storms is greater than the general average for all nonfire-starting storms, and no single average for the safe storms is less than the general average for the dangerous storms.

Tables 6 and 7 seem to demonstrate rather conclusively that fire-starting storms in this region are generally characterized by less rainfall, both ahead of and following the lightning, than safe storms which are characterized by precipitation over longer periods.

The principal purpose served by these averages in Tables 4, 5, 6, and 7 is the approximate determination of a condition which varies within wide limits, so that definite averages can be stated above which departures generally indicate less than the usual need for fire control, and below which departures indicate more need for action. The averages given, however, include both dry and wet storms. It is therefore possible to eliminate the dry storms and by considering only those which brought some rainfall, either ahead of or following the lightning, to determine the duration of the rainfall only for the wet storms. Naturally, this duration will be appreciably greater than the average determined on the basis of both wet and dry storms.

Of 7,093 reports of both classes of storms only 48 per cent state no rain ahead of the lightning. The remaining 52 per cent state an average of 25 minutes of rain ahead of the lightning. As would be expected, this is approximately double the average for both wet and dry storms. On this basis it is evident that the average storm reported as having rain ahead of the lightning may be expected to bring about 25 minutes of precipitation.

The records show that there is a smaller proportion of storms that are dry following the lightning than of those that are dry ahead of the lightning. Only 33 per cent of a total of 6,983 reports stated that no rain fell after the lightning had passed on. The other 67 per cent show an average rainfall of 58 minutes' duration. This time interval, which can be used as an additional criterion of degree of danger in this region, indicates that the "secondary rain" described by Humphreys occurs in about two-thirds of all the thunderstorms in this region, and lasts for about one hour.

Further examination of the data on rainfall ahead of the lightning, by subdivisions of the region, shows that, for each of the five groups of forests previously described, the conclusion holds true that there is less rainfall ahead of the lightning with fire-starting storms than with safe storms. Table 8 shows the averages and the number of reports on which they are based, for each of these groups.

TABLE 8.—*Record of number of minutes' rainfall ahead of lightning in fire-starting as compared with nonfire-starting storms, by forest groups, 1924–1928*

Forest group	Nonfire-starting storms		Fire-starting storms	
	Average rainfall	Reports	Average rainfall	Reports
	Minutes	*Number*	*Minutes*	*Number*
Group I	8.8	511	2.8	33
Group II	12.8	545	6.7	97
Group III	15.4	1,637	6.8	803
Group IV	18.4	749	9.6	687
Group V	14.5	693	11.3	500
Region	14.6	[1] 4,135	8.7	[1] 2,120

[1] Reports used for Table 8 are the same as used for Table 6.

In the same way the data on rainfall following the lightning (Table 9) show that in each of the five groups of forests there was less rain after the lightning in fire-starting storms than in safe storms.

TABLE 9.—*Record of number of minutes rainfall following the lightning in fire-starting as compared with nonfire-starting storms by forest groups, 1924–1928*

Forest group	Nonfire-starting storms		Fire-starting storms	
	Average rainfall	Reports	Average rainfall	Reports
	Minutes	*Number*	*Minutes*	*Number*
Group I	36.0	507	23.2	36
Group II	34.2	548	18.4	99
Group III	47.0	1,662	31.8	802
Group IV	51.0	753	28.4	687
Group V	42.9	686	35.2	514
Region	44.0	[1] 4,156	30.8	[1] 2,138

[1] The reports used for Table 9 are the same as used for Table 7.

No attempt is made in this report to determine statistically the probable error of these averages, or the significance of differences between the averages for the various groups. Apparently the actual use of the criteria by lookouts and others will not be affected at present if the regional averages are used by all forests regardless of their group, because in all cases departures from the regional averages are similarly significant in each of the groups.

DRY STORMS

Although most lightning storms bring some rain with them, so-called "dry lightning storms" are often credited with starting a large proportion of forest fires in this region. It is entirely reasonable to believe that such storms are decidedly apt to start fires if their bolts are numerous, and if they reach dry fuels on the ground. The records show, however, that only 6 to 10 of every 100 lightning storms recorded in this investigation (14,754 reports) were dry, delivering no rain whatever to the ground beneath the storm cloud. The reports (8,408) which were definite with regard to both the rainfall and the fire-starting character of the storms, showed that only 33 per cent of the dry storms were fire starters. Hence, only 2 or 3 storms out of 100 are both dry and fire starters.

The occurrence of these dry lightning storms in this region is interesting in two respects. First, these reports prove the occurrence of a type of thunderstorm not included by some meteorological definitions; and, second, the so-called dry storm is popularly credited in this region as being the most dangerous fire starter. During the 5-year period covered by this study, the tabulation of 1,238 reports of lightning storms with no rain before, with, or following the lightinng, out of a total of 14,754 reports, should remove all doubt as to dry storm occurrences. And such conditions depart decidedly from Clayton's descriptions (4) and disagree with Moore's definition of a thunderstorm (**10**). This definition reads: "The thunderstorm, so familiar to everyone, may be defined as a local rain accompanied by lightning, thunder, gusts of wind, and frequently hail." Humphrey's definition (Op. cit.), "A thunderstorm, as its name implies, is a storm characterized by thunder and lightning . . .," appears to apply more conclusively in this region.

Of the reports of absolutely dry storms, stating definitely whether or not fires resulted, 68 per cent showed that no fires resulted. Of the definite reports of wet storms, on the other hand, 66 per cent stated that no fires resulted. This close similarity refutes the popular conception that dry storms as a class are more dangerous than wet storms. It also raises a question concerning other data, previously presented, which show for the majority of lightning storms that with less rain there are more fires, and with more rain less fires.

The reason for this apparent anomaly undoubtedly lies in the nature of dry thunderstorms, in which the flashes are generally few, and nearly all confined to the clouds. The meteorological reasons for these peculiarities in activity may lie in the well-supported theories (**9**) that violent, turbulent action of large masses of drops of water forming the cloud are most favorable to the generation of lightning, and that practically continuous sheets of water (rain drops) and streaks of highly ionized air form favorable paths for the bolts. Hence, clouds too small to precipitate moisture enough to reach the earth (as in dry storms) may often be large enough and active enough to generate a few flashes which will be almost entirely confined to the clouds. Large, active, and rain-producing clouds, on the other hand, may be expected to produce a greater number of flashes, with a greater number of bolts striking the ground.

LIGHTNING

That the proportion of the lightning flashes confined to the clouds has an appreciable effect upon the starting of fires is shown by the analysis of the records bearing on this feature. Table 10 shows this for the region as a whole by years. The safe storms consistently show a higher percentage of lightning confined to the clouds than do the dangerous storms.

The significance of data concerning percentage of lightning confined to the clouds, and striking the ground, obviously would be increased if the total number of flashes per unit of time, or the total number as a storm passed over a certain spot, were known. It has been found difficult, however, to obtain such counts as accurately as desired. Consequently, this aspect of the problem can not be examined at present. Work is being done, nevertheless, to obtain this information for later use.

TABLE 10.—*Percentage of lightning flashes confined to the clouds*

Year	Nonfire-starting storms		Fire-starting storms	
	Flashes, confined to the clouds	Basis, number of reports	Flashes, confined to the clouds	Basis, number of reports
	Average per cent		*Average per cent*	
1924	73	468	61	318
1925	68	835	55	565
1926	71	854	55	442
1927	80	2,470	58	736
1928	76	860	53	670
Average and total	76	5,487	56	2,731

This summary for the region, based on 8,218 observations, shows 20 per cent more lightning confined to the clouds in safe storms than in dangerous ones. From these data it is possible to establish indexes of the degree of danger as influenced by this factor. It is apparent that as a general rule if less than half of the lightning is confined to the clouds the storm is of the fire-starting type, whereas if more than three-fourths of the lightning stays in the clouds the storm is of the safe type. Intermediate amounts probably should be considered as more dangerous than safe.

A sorting of these data by groups of forests, rather than by years, also shows uniformly that the safe storms have more of their lightning confined to the clouds than do the dangerous storms. Whereas the first report on this investigation, which covered only the data for 1924 and 1925, indicated that there might be a slightly significant difference between groups of forests in the percentage of lightning confined to the clouds, the present and more comprehensive data show rather uniform percentages. As is evident from Table 11, no group average varies more than 9 per cent from the average of any other group, and none departs more than 6 per cent from the regional averages. Apparently, the criteria of degree of danger according to the amount of lightning confined to the clouds, as established on the basis of the regional data, are applicable in each of the subdivisions.

TABLE 11.—*Percentage of lightning flashes confined to the clouds in safe and dangerous storms*

Forest group	Nonfire-starting storms		Fire-starting storms	
	Flashes, confined to the clouds	Basis, number of reports	Flashes, confined to the clouds	Basis, number of reports
	Average per cent		*Average per cent*	
Group I	72	568	50	38
Group II	76	726	55	133
Group III	77	2,235	58	1,016
Group IV	78	975	53	865
Group V	72	983	59	679
Average and total	76	5,487	56	2,731

OTHER CHARACTERISTICS

In addition to the rainfall, or lack of it, and in addition to the character of the lightning, there are other features of lightning storms which affect successful forest-fire control. These include the time of day when the storms are first seen, the prevalence of storms after dark, the passage directly over the lookout stations, and the common direction of storm movement.

When lightning storms are recognized as such during the forenoon hours, it is generally possible for a ranger or his assistant to get in touch by telephone with his various employees, including trail crews, before the resultant fires have begun to be discovered by the lookouts. This is, therefore, one possibility of obtaining greater speed in fire control.

Table 12 shows the percentage of reports by years and by groups of forests, stating that the storms were first seen during the forenoon hours.

TABLE 12.—*Storms first seen in the morning, by forest groups*

Year	Group I	Group II	Group III	Group IV	Group V	Regional average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1924	24	13	18	19	35	23
1925	17	13	25	27	25	24
1926	25	31	31	32	44	34
1927	16	17	20	23	27	22
1928	22	20	23	28	30	25
Average	20	20	24	26	31	25

The outstanding indication from this compilation, based on over 14,000 observations, is that about one storm out of four is first seen before noon, and thereby permits fire-control action early in the day if the lookout immediately reports storms to his ranger.

The consistently high percentages shown by Table 12 for all groups of forests during 1926 may be of meteorological significance, and it is hoped that the study of such phases will appeal to some meteorologists. It should be mentioned here that all of the reports, for the entire day, have been specially sorted and tabulated on an hourly basis at the request of the Spokane office of the United States Weather Bureau, so that the development of storms throughout this region may be studied intensively in relation to the twice daily synoptic weather maps. From this study it is hoped to derive considerable information of value for increasing the accuracy of future forecasts and for localizing them.

The prevalence of storms at midnight has been determined merely as an approximation of the number of storms occurring during the middle of the night. The data show the following percentages of the total number of observations, which stated that the lightning storms were occurring at that hour: 1924, 5 per cent; 1925, 3.5 per cent; 1926, 7 per cent; 1927, 4 per cent; and 1928, 4.5 per cent; average for the 5-year period, 4 per cent. The importance of storms occurring during the hours of darkness lies in the inability of the lookouts to detect the resultant fires, unless the flames are so located as to be directly visible. In the meantime, and before men can reach the spot and commence suppression, the fire may have several hours in which to spread. Furthermore, since it is very difficult at night for the lookouts to make azimuth readings of lightning bolts striking, the effects of storms at night can not be accounted for so accurately. With some 4 per cent of the storms occurring at midnight, it is obvious that an appreciable number of storms are in action during the night when close observation is extremely difficult or impossible. Compilations of future data will be made to develop more specific information on this phase of the problem.

The passage of lightning storms directly over a lookout station is important in several ways. Frequently the resultant fires will be close to the station and can be attacked immediately. On the other hand it often happens that a storm cloud whose path includes the mountain top lookout station will envelop the station and reduce visibility from that point to such a degree that the direction of lightning flashes can not be discerned and resultant fires only a half mile away are invisible until the cloud has moved by.

The reports by the lookouts show the following percentages of cases in which the storms passed directly over one or more of the lookout stations: 1924, 48 per cent; 1925, 47 per cent; 1926, 47 per cent; 1927, 42 per cent; 1928, 39 per cent. This means that in about 4 or 5 of 10 observations a storm will pass directly over some lookout station and consequently that many reports on storms will be, and frequently must be, made by stations at some distance from the storm. Hence, no method of observation should be used which depends upon the storm passing directly over the observation station.

Probably the best method of determining whether or not storms are apt to start fires near lookout stations, and the likelihood of such clouds reducing visibility from that point, will be to examine the data separately for each lookout. It is believed, however, that there is not yet a sufficient volume of reports for individual stations to warrant such a detailed sorting and tabulation. Such an analysis is planned for some future date.

One feature of storm occurrence upon which we have no dependable data is the altitudinal range of the clouds, which might influence or even control zones of lightning danger as Ward (**14**) has described them on the authority of F. G. Plummer (**12**). These zones are specifically defined as being areas of lightning danger, but it is implied that high mountain tops may be above the clouds and so in a zone of safety. To investigate the occurrence of lightning-fire zones the locations of several thousand lightning fires in the northern Rocky Mountain region have been plotted on maps by H. R. Flint, in charge of fire control of the Forest Service in this region. Although these maps show conditions for more than 10 years, there is not any consistent evidence that lightning fires occur in zones limited altitudinally in any way, except by the absence of inflammable material, and by the wetness of these fuels. There is, instead, a most baffling scattering of these fires which renders the problem of successful control all the more difficult. It is recognized that these maps show merely the occurrence of lightning-caused fires and, therefore, not all points struck by lightning, but this appears to be the best information available.

Flint is also making a study of the occurrence of lightning fires in relation to mineral-bearing areas in an effort to determine whether or not geological formations have any appreciable effect upon lightning strokes and fires. The Forest Service fire records and the geologic maps for the Coeur d'Alene region are being used for this work.

Another characteristic of lightning storms that may have meteorological significance which will be of value in prediction is the common direction of storm movement in different parts of the northern Rocky Mountain region. There are 14,595 reports which serve for determining this characteristic of storms for this region. Tables 13 and 14 show the results of the analysis by years and by groups of forests.

Table 13.—*Direction of movement of storms, by years, toward the directions given*

Movement of storm	1924 reports		1925 reports		1926 reports	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
North	196	16	333	13	267	12
Northeast	456	36	891	36	671	31
East	371	29	762	31	651	30
Southeast	80	6	215	9	199	9
South	36	3	70	3	89	4
Southwest	36	3	64	3	91	4
West	31	3	52	2	73	4
Northwest	40	3	87	3	89	4
Stationary or revolving	18	1	7	0	34	2
Total	1,264	100	2,481	100	2,164	100

Movement of storm	1927 reports		1928 reports		Total reports	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
North	461	11	451	10	1,708	12
Northeast	1,207	28	1,233	28	4,458	31
East	1,383	32	1,403	32	4,570	31
Southeast	425	12	714	16	1,731	12
South	248	6	259	6	702	5
Southwest	140	3	134	3	465	3
West	107	3	79	2	342	2
Northwest	158	4	100	2	474	3
Stationary or revolving	47	1	39	1	145	1
Total	4,274	100	4,412	100	14,595	100

Table 13 clearly shows the marked tendency of lightning storms to travel toward the northeast and east in this region. Only 12 per cent of the reports show a movement toward the north, and the same proportion toward the southeast, all other directions being credited with only 5 per cent or less. The changes from year to year during the period studied do not appear to be significant.

Table 14 indicates that there are no marked differences in direction of storm movement between the various groups of forests. While Group I, in the northeastern part of the region and largely east of the Continental Divide, shows the highest percentage of movement toward the east, Group V, in the southwestern part of the region, shows the greatest movement toward the north and northeast. The significance, if any, of these differences is a problem for the meteorologists. Perhaps these data serve as an index of the probability of summer rain, from each cardinal direction, but the practical application of such information in fire control is doubtful.

TABLE 14.—*Direction of movement of storms, by forest groups (movement toward the directions given)*

Movement of storm	Group I reports		Group II reports		Group III reports	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
North	55	7	146	11	694	11
Northeast	281	34	396	31	1,514	25
East	339	42	503	39	1,918	31
Southeast	57	7	115	9	975	16
South	22	3	41	3	391	6
Southwest	17	2	26	2	231	4
West	14	2	37	3	148	2
Northwest	24	3	33	2	217	4
Stationary or revolving	2	0	2	0	57	1
Total	811	100	1,299	100	6,145	100

Movement of storm	Group IV reports		Group V reports		Region reports	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
North	424	12	389	13	1,708	12
Northeast	1,003	29	1,264	43	4,458	31
East	1,006	29	804	28	4,570	31
Southeast	388	11	196	7	1,731	12
South	198	6	50	2	702	5
Southwest	137	4	54	2	465	3
West	102	3	41	1	342	2
Northwest	121	4	79	3	474	3
Stationary or revolving	57	2	27	1	145	1
Total	3,436	100	2,904	100	14,595	100

One other feature of the movement of lightning storms has a possible bearing on fire control. This concerns the possible tendency of storms to follow more or less regular paths, perhaps according to the topography or the local presence or absence of thunderstorm-breeding conditions, as Brooks (**3**) and Hallenbeck (**7**) have described them.

Naturally, the determination of localities most frequently exposed to lightning storms is of great importance in deciding upon the forest protection facilities that should be provided for different areas. Field observers in this region are strongly of the opinion that certain topographic features and localities are common centers of formation of storms and that there are certain paths of movement which are followed much more frequently than other paths. The present records covering all subdivisions of the region have not been exhaustively examined, but detailed analyses have been made of several restricted areas, comprising up to about a million acres, and for some of the most dangerous days thunderstorm reports for the entire region have been plotted on maps. These minor studies have failed to find any marked topographic paths along which thunderstorms may commonly be expected to travel. It is planned to investigate these conditions more intensively a few years hence, after the volume of records from each station has increased materially.

LIGHTNING-CAUSED FIRES

The number of lightning fires per unit of area is a basic consideration for forest-protective agencies. This figure is not the same for different parts of the United States, nor even for different parts of the northern Rocky Mountain region, being governed largely, as has been seen, by the number and characteristics of storms.

When storms are accompanied by more rain than the average and when they have more than the usual amount of lightning confined to the clouds, a smaller proportion of them cause fires. When they are accompanied by less rain than the average, however, and have most of the lightning striking the earth a larger proportion is dangerous. Though the seasonal wetness or dryness of the forest fuels undoubtedly influences the probability that a storm of certain character may start fires, the two conditions, occurrence of storms (as indicated by number of thunderstorm days) and the characteristics of storms (as shown by percentage of storms starting fires) are essentially indicative of the lightning fire hazard per unit of area in a given timber type in this region.

The relationship between storm occurrence, characteristics, and the number of resultant fires can be expressed as a simple formula which, when applied to the data for each of the five regional subdivisions, serves to compute the average number of lightning fires per unit of area with a maximum error of one and one-half fires per 100,000 acres. The formula used was $\frac{10b}{a}=c$. The data are shown in Table 15.

TABLE 15.—*Thunderstorm occurrence, danger and fires*

Forest	Average thunderstorm days per year (a)	Reports showing storms starting fire (b)	Actual lightning fires per 100,000 acres per year	Computed lightning fires per 100,000 acres per year (c)
	Number	*Per cent*	*Number*	*Number*
Group I	56	6	1	1
Group II	43	15	2	3½
Group III	62	31	6	5
Group IV	50	47	11	9½
Group V	57	41	6	7
Region	87	34	5	4

The data in Table 15 show again that occurrence of storms is not, by itself, a satisfactory index of the degree of danger of lightning fires. Before the degree of lightning-fire danger can be estimated satisfactorily fire weather forecasts must consider other factors—the characteristics of the storms and probably the seasonal and current moisture content and inflammability of the forest materials. As has been shown, these conditions can be observed and measured with sufficient accuracy to improve very greatly the knowledge of probable danger. The combination of conditions resulting in the highest degree of local danger consists of numerous storms of the fire-starting type covering a small and often inaccessible area on which the fuels are extremely dry.

Table 15 also shows the relative danger of lightning storms for the region and for each of its subdivisions. For the region as a whole about 34 storms out of 100 are dangerous, while for the subdivisions this figure varies from 6 to 47. The actual average number of fires per unit of area show that the importance of the lightning problem varies more nearly with the percentages of storms starting fires (i. e., storm characteristics) than with mere storm occurrence.

There is one other feature of lightning fires which is of great importance in successful fire control. This is the period of time which commonly elapses between the first sighting of a storm by a lookout and the discovery from the same station of each of the resultant fires. It is obvious that if a storm is sighted some hours before the fires it started are discovered, such a period offers greater opportunity for the lookout to inform his ranger of the path of the storm, the probability of fires, and even the probable location of fires, according to his observations of where lightning is striking. Likewise, a long period offers the ranger more time to request an air patrol of his district, and more time to communicate with his fire guards, smoke chasers, patrolmen, and road, trail, and telephone construction or maintenance crews, so that they may move to more strategic locations if the ranger desires. All this will assist greatly in catching fires while small—the first essential in effective fire control. Prompt and well-advised action is therefore required, especially when not enough men are regularly employed to attack an exceptional number of fires efficiently. Speed and dependable information are even more important in the region under study than elsewhere, because here are several national forests with an average of only 16 to 18 miles of road and trail per township of 23,040 acres, and measured travel off the trail is at the seemingly low average rate of only 1 mile per hour. Under such conditions it is extremely desirable to grasp all opportunities for moving men as early as possible to locations from which a minimum of travel will be required to reach the fires.

As an index of the time available for reporting on the important features of lightning storms before the fires are detected, 4,149 reports state definitely the time when the storm was first seen and the hour and minute when the fires were discovered. Of these 2,338 reports show the time between first sighting the storm and the discovery of the first fire, 959 reports state the time before discovering the second fire, 538 reports cover a third fire, and 314 give data for a fourth. The results have been arranged to represent conditions for an average lookout station and show the probability of a first discovery of a fire within definite periods of time after sighting the storm, or if two fires are discovered the probable elapsed time for the second discovery and similarly for third and fourth fires. The records show that occasionally a single lookout has reported 10 or 12 fires caused by one lightning storm, but the majority of the reports show far less than this.

When the cumulative percentage of discoveries were plotted by hourly periods (hours following the first sighting of the storm) and the data were curved, the values given in Table 16 were obtained.

TABLE 16.—*Percentages of storm reports showing various intervals between sighting of storm and discovery of subsequent fires*

Hours after first sighting storm	First fire	Second fire	Third fire	Fourth fire
	Per cent	*Per cent*	*Per cent*	*Per cent*
0 to 1	20	16	12	8
1 to 2	16	12	12	13
2 to 3	11	11	10	8
3 to 4	8	9	9	6
4 to 5	5	6	5	4
5 to 6	4	4	5	4
6 to 12	12	14	15	16
12 to 18	7	8	8	11
18 to 24	5	6	6	7
24 to 48	5	6	8	9
Over 48	7	8	10	14
Total	100	100	100	100

Table 16 shows that the period of time between first sighting the storm and the discovery of fire lengthens very appreciably with each subsequent fire. For example, about half the first fires are discovered within three hours after the lookout first sees the storm. In other words, to be amply prepared to reach and hold as many as half of the first fires, only three hours is available for presuppression action after the storms are sighted. Four hours can be allowed for equal preparation for second fires, five hours for third fires, and over six hours are available for the majority of the fourth fires. The importance of these determinations lies in the fact that regardless of whether or not lightning storms have been previously predicted by the Weather Bureau, there is, after the storm actually appears, a very appreciable period of time available to mobilize men and otherwise prepare for the probable fires. Obviously, in regions like northern Idaho, where 4 or 5 storms out of 10 usually start fires, such an opportunity for preparation is decidedly desirable.

Another important fact indicated in Table 16 is the considerable number of discoveries of fire made only after a lapse of 48 hours. For the region as a whole, for the 5-year period, 333 reports show this so-called "hang-over" condition. These reports comprise 8 per cent of the reports studied, and it is worth mentioning here that in 160 instances in these reports these hang-overs were first discoveries. Consequently, it is obvious that even though a lightning storm passes by and no fires are discovered within the following two days, there is still an appreciable chance that fires, were started and will show up later on.

TABLE 17.—*Percentage of fires discovered 48 hours or more after the storm was first seen*

Year	First fire	Second fire	Third fire	Fourth fire
	Per cent	*Per cent*	*Per cent*	*Per cent*
1924	8	3	1	4
1925	10	15	20.5	23
1926	6.5	12	15	20
1927	6	5	8	15
1928	5	4	4	6
Average	7	8	10	14

Table 17 shows that since 1925 there has been a consistent reduction in the percentage of discoveries made more than 48 hours after the storm appeared. Whether this has been brought about by the establishment of more lookout stations directly surveying more area, the removal of old stations to new and better locations, or by better trained and more conscientious personnel can not be determined from these reports. A marked and very desirable improvement in fire control is evident, nevertheless.

When the speed of detection is compared for the five subdivisions of this region the most outstanding fact is that the Beaverhead-Helena group of forests, which has very few lookout stations at high elevations, shows a consistently longer period of time between sighting the storm and making the first discovery of a fire. For example, four hours after the storm appears only 50 per cent of the first discoveries have been made on the Beaverhead-Helena group, while 60 per cent have been made on the north Idaho forests comprising Group IV. Twelve hours after the storm is first seen the eastern Montana forests have made only 66 per cent of their first discoveries, while Group IV has made 77 per cent and Group V 79 per cent. At the 24-hour mark the Beaverhead-Helena have only 74 per cent to their credit, while Groups IV and V have 89 per cent and 90 per cent, respectively.

In this region there are two other observations which have also been found of immediate value and usefulness. The first is the measurement of azimuths or compass bearings on points struck by lightning and the recording of these measurements so that these spots can be watched very carefully for at least 48 hours to come. (A special form is provided for noting such observations.) As a result of such action many fires may be discovered as soon as the first wisp of smoke rises from the spot and hours before the usual smoke column begins to be clearly visible. The second observation is whether the spots struck by lightning are well soaked, lightly sprinkled, or entirely unmoistened by the storm. Experience has shown that even with storms bringing heavy rainfall lightning may strike one or more places near the edge or even outside the area wetted. Naturally, if the fuel types are similar, a bolt falling outside the rain area will have a better chance of starting a fire than one at a spot which is thoroughly soaked by rainfall. But of even more importance is the fact that if fires result in both cases the one outside the rain area is much more in need of immediate attention than the one that is surrounded by wetter fuels, and the former should be attacked first if there must be a choice. Usually the lookout is the only member of the forest protective organization who is in a position to make this important fact known to the ranger, central dispatcher, or whomsoever may be responsible for sending men to these fires.

SUMMARY

Because lightning is the most important single cause of forest fires in the northern Rocky Mountain region a special study has been made by the Forest Service of the occurrence and characteristics of lightning storms in that region. This study utilized the data obtained from fire lookouts stationed on approximately 200 mountain tops, so distributed that very few storms could occur during the summer months without being reported by the lookouts. A special form was used for obtaining the desired information, which is now summarized for the 5-year period 1924 to 1928, inclusive.

The results show that about 34 storms out of 100 have caused forest fires and that there are from two to four times more thunderstorm days per year in this region than had been previously estimated. It is found, however, that the danger of forest fires caused by lightning is not in proportion to the number of thunderstorm days but varies more with the characteristics of the storms. The greatest number of fires and the greatest proportion of reports of fire-starting storms were found on 20 days, which constitute only 4 per cent of the total number of thunderstorm days. Records are included so that these so-called easy and bad days may be studied in relation to the daily weather maps.

An analysis of the 14,754 lookout storm reports available shows that there are recognizable differences between the types of storm that usually start fires and the types that are generally safe. These differences are found to lie in the duration of the rainfall ahead of and following the lightning, together with the electrical activity of the storm and the percentage of lightning flashes confined to the clouds or striking to the earth. Average duration of rainfall, and average percentage of lightning flashes striking to the ground, have been determined separately for the safe and for the dangerous storms. It is pointed out that by observing these characteristics it is often possible for the lookouts to classify a storm as either generally safe or generally dangerous hours before any of the resultant fires produce enough smoke to permit discovery. Such advance information permits the forest protective agency to move men into or near the danger area so that the fires can be reached more quickly and be extinguished more cheaply while yet small.

It is found that the so-called dry storm (having no rainfall reaching the ground) occurs in only 6 to 10 cases out of 100. Of all these dry storms only one-third started fires, whereas one-third of the wet storms were also dangerous. The reasons for this anomaly are believed to be in the lesser number of lightning flashes in dry storms together with a lesser proportion of these flashes reaching the ground. Naturally, no fires can be started by a dry storm if all of the lightning is con fined to the clouds.

* * * * *

From these facts, developed by the analysis of the reports on lightning storms, it is obvious that there are four observations which forest-fire lookouts can make which are of immediate value to the forest ranger directly in charge of fire control: (1) The occurrence of storms; (2) their paths: (3) the accompanying precipitation, if any; and (4) the percentages of lightning confined to the clouds and striking the ground. Always, the flash of lightning or the rumble of thunder will be the best assurance of thunderstorm occurrence, but usually the formation of cumulus clouds of the thunderstorm type and size is sufficiently definite, especially if storms have been predicted by the Weather Bureau. As the storm develops and the lookout is able to estimate its probable path he may be able to determine whether the particular ranger district which includes the lookout station is apt to be affected. If it is, then some prominent topographic feature will serve to time the duration of rainfall and to estimate the character of the lightning as the storm passes over that point. Such information, obtained by a careful observer, is now recognized as an excellent basis for fire control action in the northern Rocky Mountain region.

Some other characteristics of storms determined by this study include the finding that 25 per cent of the storms are first seen before noon; about 4 per cent of the storms are active during the middle of the night; only 4 or 5 observations out of 10 report the storm as passing directly over the observation station, thereby indicating the local character of lightning storms in this region; 62 per cent of all thunderstorms in the northern Rocky Mountain region move toward the northeast and east, while 86 per cent are found to travel in a direction between north and southeast; no common topographic paths of travel have as yet been discernible.

This study is to be continued, using an improved report form to obtain additional detail of information as well as to record if possible any increase or decrease in the occurrence of lightning storms over a longer period.

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THE CALENDAR YEAR AS A TIME UNIT IN DROUGHT STATISTICS[1]

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As almost everyone knows, the year is generally considered as being too long a unit for use in compiling drought statistics. While admitting the general soundness of that view, it is believed that the disadvantages of the calendar year have been somewhat exaggerated. The case of Arkansas in 1930, when the percentage of the normal precipitation received was 96 per cent, will naturally come to mind. In this case two of the months, January and May, had 223 and 200 per cent of the normal, respectively, and the real lack of rain that caused the failure of the cotton crop was confined to the months of June and July, with 22 and 19 per cent, respectively. Most persons fail to consider that the very great rainfall of January and May was in itself quite abnormal and not likely to again happen in the next 50 years.

The reason why a shorter period than the year has not heretofore been used in compiling drought statistics is most likely because of the overlapping of drought periods from one month to the next and the fact that its ending rarely occurs at the end of a month; thus it would be necessary to make a special compilation in order to fix the definite limits of the duration of droughts. This has not been done, and to do it now for previous droughts is prohibitive on account of the labor involved.

The object of the present compilation was therefore to ascertain to what extent the calendar-year record of precipitation would serve to accurately fix the times and places of drought in the United States. In the beginning of the study the individual records of stations within a State using both the monthly and annual amounts were used. As the work progressed the difficulties of distinguishing the beginning and the ending of drought even from the monthly totals of precipitation led to its abandonment and the substitution of a shorter method based on the averages of precipitation for each year for each of the 42 districts organized into what were formerly known as State weather services, now known as climatological sections, of which as a rule there is one in operation for each State or combination of States, except that the six New England States are organized under the name "New England," and Delaware and the District of Columbia are combined with Maryland. The list of sections with the term of years covered by each section is given in Tables 1 and 2.

In some of the sections the record goes back to the early eighties and in others it does not begin until about 1900, so that the early part of the period is not as fully covered as that part subsequent to 1900. The size of the respective sections varies greatly—say, from about 15,000 square miles in the smallest to 265,896 in the largest. The network of climatological stations is somewhat closer east of the Mississippi than to the westward, especially in Rocky Mountain and Plateau States.

The plan followed was to take out for each State the least annual precipitation that had been recorded during the forty-odd years during the life of the record, then the next lowest annual amount, and so on, on an ascending scale until the tenth year on that scale had been reached. Thus it has been practicable to construct for each State a diagram beginning at the low point and increasing to, say, about 90 per cent of the annual average precipitation. In like manner the year of greatest annual precipitation has been taken out and the nine subsequent years when the next greatest annual amount was received, and so on until the tenth year, on a decreasing scale, had been reached.

Tables 1 and 2 include the tabulation above described, the annual amounts of precipitation being expressed as a percentage of the mean annual or, in other words, the normal for the State.

In Table 1 the scale is an increasing one and in Table 2 a decreasing one.

[1] The substance of this article was presented before the May, 1931, meeting of the American Meteorological Society in Washington, D. C.